



OPTIONS AND GAMES

BENOÎT CHEVALIER-ROIGNANT AND LENOS TRIGEORGIS

Competitive Strategy

Options and Games

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Competitive Strategy

Glossary

Accommodated entry Entry is accommodated if structural entry barriers are low and entry-deterring strategies are ineffective or too costly. An incumbent attempts to adopt strategies and build competitive advantage early on to cushion the future negative effects of accommodated competitive entry.

Action An action or move by one of the players in a simultaneous game is a choice or decision she can make that affects the other player(s).

Barriers to entry Barriers or factors that allow an incumbent firm to earn positive economic profits or excess rents by making it unprofitable for newcomers to enter the industry. Competitive markets are characterized by low entry barriers.

Blockaded entry A condition where the incumbent need not undertake any entry-deterring strategies to enjoy monopoly rents in the marketplace. Structural or administrative barriers are sufficient conditions for blockaded market entry.

Call option A contract or situation that gives its holder the right, but not the obligation, to buy or acquire an underlying asset at a predetermined price over a specified period (maturity).

Chicken game See “war of attrition.”

Closed-form solution A solution that gives an analytical answer to a mathematical formulation.

Closed-loop strategies In dynamic games, closed-loop strategies allow players to condition their play on both the previous moves by the players and on calendar time. All past actions of all players is common knowledge at the beginning of each stage.

Closed-loop equilibrium The equilibrium forms a perfect equilibrium in closed-loop strategies; that is, the closed-loop strategies form a Nash

equilibrium in each and every subgame (on and off the equilibrium path).

Commitment See “strategic commitment.”

Commitment value The incremental value (positive or negative) accruing to a firm from making a strategic commitment.

Cost advantage One of the main strategies to achieve a competitive advantage is to seek to attain lower costs, while maintaining a perceived benefit comparable to that of competitors. A relative cost advantage influences the optimal investment timing of competing firms.

Cost of capital The rate of return expected or required by an equally risky asset or investment to induce investors to provide capital to the firm. The cost of capital reflects the systematic (or market) risk of a traded asset perfectly correlated with the investment or asset to be valued.

Deterred entry A situation occurring when an incumbent can keep an entrant out by employing an entry-detering strategy.

Dominant strategy A strategy that is the best decision for a player regardless of the action or strategy chosen by its opponent.

Early-mover advantage An advantage from moving early that enables a firm to make a higher economic profit than its rivals. An early-mover advantage can stem from the uncontested market presence of a leader that enjoys monopoly rents for some time. Sources of sustainable early-mover advantages include the learning-curve effect (economies of cumulative production and learning), brand-name reputation—especially in situations where buyers are uncertain about product quality (“experience goods”)—, or high customer switching costs.

Economic profit A profit concept that represents the difference between the profits earned by investing resources in a particular activity and the profits that would have been earned by investing the same resources in the best alternative activity in the market. Opportunity costs are subsumed in economic profits.

Economies of scale Cost savings achieved when the unit production cost of a product decreases with the number of units produced.

Economies of scope These involve cost savings externalities among product lines or production activities.

Elasticity The elasticity of a variable with respect to a given parameter is the percentage change in the value of the variable resulting from a one

percent change in the value of the parameter, all other factors remaining constant.

European option An option that can only be exercised at maturity, not earlier.

Extended (or expanded) net present value (E-NPV) The total value of a project including the option or flexibility value and the impact of any strategic commitment or interaction effects.

Fixed costs Costs that are independent of the scale of production and are locked in for a given period of time. Some distinguish among fixed and sunk costs though the difference is subtle: “fixed” often refers to short-term commitments, while “sunk” or nonrecoverable costs generally involve a longer planning horizon.

Focal-point argument In the event of multiple equilibria, the focal-point argument suggests that an equilibrium that appears “natural” or logically compelling is the one more likely to arise.

Games of incomplete information Games where players do not know some relevant characteristics of their opponents (e.g., their payoffs, available action sets or their beliefs).

Games of perfect information Games where all players possess all relevant information. Extensive-form games of perfect information have the property that there is exactly one node or decision point in each information set.

Game theory A branch of mathematics and economic sciences concerned with the analysis of optimal decision-making in multiplayer settings. Chess is a well-known example. Solution concepts meant to provide predictions on the likely outcomes impose certain behavioral restrictions on players.

Information set The information a decision maker has at the moment she makes a decision.

Isolating mechanisms Economic forces put in place by a firm to limit the extent to which its competitive advantage can be duplicated, eroded, or neutralized through the resource-creation activities of competitors.

Learning-curve effect Learning-based cost advantage that results from accumulating experience and know-how in productive activities over time.

Market structure Characteristic of a market in terms of number and size (power) distribution of firms. Monopoly, duopoly, and perfect competition are classic examples of market structure.

Markov property This property asserts that for certain stochastic processes or dynamic problems, all the past relevant information is summarized into the latest value of a variable or price. One cannot therefore use past information to predict the future state of the variable. Efficient markets and Itô processes have this Markov property.

Maturity The period or last moment at which an option can be exercised. If the option can be exercised before this date, it is called an American option; if only at maturity, a European option.

Myopic strategy A strategy that does not take into account or is independent of the investment decisions of rivals.

Nash equilibrium A classic equilibrium solution concept used in the analysis of multiplayer games: each player pursues its individual optimizing actions given the best actions of the other players. In equilibrium, no player has an incentive to unilaterally deviate.

Nature Acts of nature are treated as the actions of a quasi-player that makes random choices at specified points in a game.

Net present value (NPV) The NPV paradigm is well established in corporate finance. The net present value of a project is the present value of the expected cash flows minus the (present value of) required investment costs. In the absence of managerial flexibility, a stand-alone investment is deemed acceptable if its net present value is positive.

Node A decision point in a game at which a player (or nature) can take an action.

Open-loop strategies Strategies where players cannot observe the previous play of the opponents and therefore condition their play on calendar time only. Such strategies are also called “precommitment strategies.”

Open-loop equilibrium A Nash equilibrium solution that is obtained when firms adopt open-loop strategies ignoring their rivals’ actions over the history of the game.

Option A contract or situation that gives its holder the right but not the obligation to buy or acquire (if a call) or sell (if a put) a specified asset (e.g., common stock or project) by paying a specified cost (the exercise or strike price) on or before a specified date (the expiration or maturity date). If the option can be exercised before maturity, it is an American option; if only at maturity, a European option.

Option to invest or option to defer An American-type call option embedded in projects where management has the right (but no obliga-

tion) to delay the project start for a certain time period. The exercise price is the cost needed to initiate the project.

Option valuation Valuation process by which the total value or “expanded net present value” (E-NPV) of an investment opportunity is determined. The valuation approach is meant to capture management’s flexibility to adapt its decisions to the evolving uncertain circumstances.

Path dependence A situation occurring when past circumstances or history condition the current outcome and can preclude or favor certain path evolutions in the future.

Payoff The utility, reward, or value a player receives when the game is played out. In the option games context, the payoff can be the real option value (e.g., the value of a plant with the option to expand production).

Perfect Nash equilibrium See “subgame perfect Nash equilibrium.”

Players The individuals, firms, or actors that make decisions in a game situation. Each player’s goal is to maximize her payoff or value by choosing the best action or sequence of actions (strategy).

Precommitment strategies See “open-loop strategies.”

Preemption A situation whereby a firm invests ahead of its rivals to hinder their entry or profitable operation. Such a situation is often related to the presence of some first-mover advantage.

Proprietary option An option held by a firm that entitles it to the full exclusive benefits resulting from exploiting the option. A monopolist firm has a proprietary investment option.

Real option The flexibility arising when a decision maker has the opportunity to adapt or tailor a future decision to information and developments that will be revealed in the future. A real option conveys the right, but not the obligation, to take an action (e.g., defer, expand, contract, or abandon a project) at a specified cost (the exercise price) for a certain period of time, contingent on the resolution of some exogenous (e.g., demand) uncertainty.

Real options analysis The field of application of option-pricing theory to valuing real investment decisions.

Risk-neutral valuation A valuation method underlying option pricing analysis that adjusts for risk in the expectation of cash flows (certainty-equivalent), enabling discounting of future values at the risk-free interest rate. This contrasts to the standard valuation approach (NPV) consisting

in discounting the (actual) expected cash flows at a (higher) risk-adjusted discount rate.

Risk neutral Situations where investors are indifferent between a sure payoff (certainty-equivalent) and a risky outcome of equal expected value. By extension, the same description is used for the corresponding valuation method.

Shared option An option simultaneously held or shared by several firms in the industry. Shared options characterize competitive industries where incumbent firms share the same investment opportunities. Shared options are more involved to analyze as they must account for rival reactions or interactions. Option holders' investment behavior and project values are affected by the proprietary or shared nature of real options.

Soft commitment (or accommodating stance) A strategic investment commitment that makes the rival firm better off in the (later) competition stage. In Cournot quantity competition, a soft commitment leads the committing firm to produce relatively less, while in Bertrand price competition a soft commitment induces the firm to maintain a higher price.

Stochastic processes A set or collection of random variables such that the value of the process at any future time t is random though specified by a given probability distribution.

Strategic commitment A strategic decision or move intended to alter the competitors' behavior or beliefs about future market competition. Such commitments are generally difficult or costly to reverse.

Strategic complements (or reciprocating actions) These characterize actions in situations where firms react (in equilibrium) in a reciprocating or complementary manner (i.e., reaction functions are upward sloping). For example, I will be nice to you if you are nice to me. In case of price competition, price-setting actions are strategic complements.

Strategic substitutes (or contrarian actions) These characterize actions in situations where firms react (in equilibrium) in a contrarian or opposite manner (i.e., reaction functions are downward sloping). For example, you take advantage of me if I am nice to you. In case of quantity competition, capacity-setting actions are strategic substitutes.

Strategy A behavioral rule adopted by a player that prescribes which contingent action(s) to choose at each stage in a game. A strategy specifies for each decision node or information set which action to pursue. Open-loop and closed-loop strategies refer to different strategy types:

open-loop strategies make more restrictive assumptions on the information the players possess over the game play.

Subgame perfect Nash equilibrium Solution concept used in dynamic games under complete information: (continuation) strategies form a Nash equilibrium at each and every stage of the game—even those stages that will not be actually played in equilibrium (“off the equilibrium path”).

Sunk costs Investment costs that cannot be recouped. Once incurred, sunk costs are irrelevant for future decision-making.

Tough commitment (or aggressive stance) A strategic commitment intended to hurt the rival. In Cournot quantity competition, tough commitment induces the committing firm to produce more, while in Bertrand price competition the firm will cut its price and enter a price war.

Variable costs Costs, such as direct labor or commissions to sales people, that vary as the output level rises.

War of attrition (or chicken game) In a duopoly involving a second-mover (follower) advantage, both firms have an incentive to be a follower or wait to be the last to move, leading to a “war of attrition.”

Symbols

i, j	Competing firms (in a duopoly)
$-i$	All other firms except firm i (in oligopoly)
n	Number of firms (in a competitive industry or market)
$\pi_i(\cdot)$	Firm i 's certain (deterministic) profit function
$\tilde{\pi}_i(\cdot)$	Firm i 's uncertain (stochastic) profit function
$p(\cdot)$	Deterministic (inverse) demand function
$\tilde{p}(\cdot)$	Uncertain (inverse) demand function
a, b	Known constant parameters in the (inverse) demand function
q_i	Quantity produced by firm i
Q	Total quantity produced by all firms in the industry
c_i	Firm i 's variable (unit) cost
K_i	Up-front strategic investment outlay by firm i (in commitment games)
s	Degree of substitution (in differentiated Bertrand price competition)
x	R&D effort (in R&D investment games)
γ	Degree of R&D spillover (sharing) effects
k	Risk-adjusted discount rate (cost of capital)
r	(Instantaneous) risk-free interest rate
δ	Asset cash flow or dividend yield, convenience yield (for commodities), competitive erosion, or opportunity cost of waiting
g	Actual growth rate (drift parameter) for geometric Brownian motion
\hat{g}	Risk-neutral growth rate (for geometric Brownian motion)

α	Actual growth rate for arithmetic Brownian motion
$\hat{\alpha}$	Risk-neutral growth rate for arithmetic Brownian motion
σ	Volatility (for the arithmetic or geometric Brownian motion)
h	Small time interval
dt	Infinitesimal time interval ($h \rightarrow dt$)
q	Actual (empirically observed) probability (of up move)
p	Risk-neutral probability (of up move)
u	Up-move multiplicative factor in a binomial tree (process)
d	Down-move multiplicative factor in a binomial tree (process)
I_i	Investment outlay (cost) for firm i
e	Expansion factor (base value V expanded by e percent upon paying investment cost I , giving $eV - I$)
λ	Poisson jump arrival rate (frequency)
ρ	Correlation coefficient
$E_0[\cdot]$	Expectation based on actual probabilities (conditional on time-0 information)
$\hat{E}_0[\cdot]$	Risk-adjusted expectation based on risk-neutral probabilities (conditional on time-0 information)
$\text{var}(\cdot)$	Variance (or σ^2)
t_0	Starting time
t	Current time
T	Time (years) to maturity of the option (in discrete-time models)
\tilde{T}	random first-hitting time (i.e., the random time at which the pre-set investment trigger X_T is first reached)
\tilde{T}^*	Optimal random first-hitting time (i.e., the random time the optimal investment trigger X^* is first reached)
$B_t(\tilde{T})$	Value (at time t) of a bond paying 1 euro at random future time \tilde{T} . It also represents the expected discount factor.
z_t	A standard Brownian motion or Wiener process
ε_p	Price elasticity of demand ($\varepsilon_p(Q) \equiv -[\partial Q/\partial p] \times (p/Q)$)
β ($\hat{\beta}$)	Dummy variable of the fundamental quadratic function ($\hat{\cdot}$ for the risk-neutral version)
β_1 ($\hat{\beta}_1$)	Positive root of the fundamental quadratic function (elasticity of the option to invest)

β_2 ($\hat{\beta}_2$)	Negative root of the fundamental quadratic function (elasticity of the option to exit)
x_0	Time-0 value of the stochastic process in the case of arithmetic Brownian motion
\tilde{x}_t	Stochastic process value at time t in the case of <i>arithmetic</i> Brownian motion ($\tilde{x}_t \equiv \ln(\tilde{X}_t)$)
X_0	Time-0 value of the stochastic process in the case of geometric Brownian motion
\tilde{X}_t	Time- t value of the process in the case of geometric Brownian motion
X_T	Value of the stochastic process at maturity T in discrete-time option games, or the preset investment trigger—not necessarily the optimal one—in continuous-time option games
X^*	Optimal investment trigger (*)
M	Monopolist firm's total value (with investment timing or expansion option)
S	Total firm value (with investment timing or expansion option) in an oligopoly characterized by simultaneous investment
L	Leader's value (with investment timing or expansion option) in sequential investment option games
F	Follower's value (with investment or expansion option) in sequential investment option games
*	(Superscript) denotes optimal or equilibrium value
\wedge	(Superscript) denotes risk-neutral or risk-adjusted expectation, variable or parameter
€	Euro
M	Million
Bn	Billion
\equiv	Means “is defined to be”

Foreword

President Truman once said: "Give me a one-handed economist. All of my economic advisers say 'On the one hand this, on the other hand that.'" Economists do indeed recognize that there are multiple forces at work in most situations, and it takes quite subtle analysis to understand their interaction and balance. This book is an admirable effort at such an economic analysis.

When facing an uncertain future, remaining flexible until more information arrives has value, because one can cherry-pick to make investments only when the prospects are relatively favorable. This is the starting intuition of real option theory. But in game theory, the strategy of making irreversible commitments to seize first-mover advantage and present rival players with a *fait accompli* to which they must adapt can have its own value. So what does one do when facing an uncertain future in the company of rivals? This is a difficult problem, conceptually as well as mathematically. The last two decades have brought a trickle of research contributions that address some aspect of this dilemma. In this book, Benoît Chevalier-Roignant and Lenos Trigeorgis synthesize and consolidate much of this literature and skillfully extend it. Generations of students and researchers over the next decade or two will find the book an invaluable starting point for their own work.

The authors also deserve congratulations for their excellent exposition. They begin with very simple and clear overviews of the issues, concepts and models from the separate areas of real options and game theory. They focus on applications to industrial organization and business. For students in any of these areas, this book can serve as a hyper-market for one-stop intellectual shopping.

I will endeavor a personal remark. I was involved in some of the early research on real option theory. I also contributed to popularizing game theory. But I seem to suffer from a kind of attention-deficit disorder in

research; therefore I got interested in, and diverted to, other fields like political economy and governance institutions. I am happy that my contributions to real option theory are still remembered, and feel honored to be asked to write a preface to this book. But, returning to the real options literature after many years to read this book, I also feel like Rip Van Winkle, amazed at how much has changed in the intervening years. Although I have enjoyed my excursions into other fields, perhaps I should have stayed and contributed to these equally exciting developments that have combined options and games to produce better two-handed economists.

Avinash Dixit
 Princeton, NJ
 June 2010

Preface

In real life most situations corporate managers face are characterized by both strategic and market uncertainties with respect to the economic environment. Following the liberalization and deregulation of Western economies, very few industries remain protected, whereas most companies face fierce competition in their respective economic sectors. Certain European governments used to favor high administrative barriers shielding certain “natural monopolies” from competitive entry. Such protected monopolies included the telecommunications, electricity, and gas sectors. European governments recently had to enforce deregulation schemes, opening up many economic activities to new, potentially foreign market participants. At the same time sectors traditionally populated by many firms have undergone significant consolidation, yielding oligopolistic situations with a reduced number of players. These two ongoing concurrent phenomena—liberalization and continuing consolidation—highlight the emphasis corporate managers increasingly put on *strategic uncertainty* and market structure.

Besides strategic uncertainty, managers face increasing *market uncertainty*. With a reduced life cycle for many products, firms can no longer rely on a given offering but have to renew their product portfolio frequently to sustain or enhance their revenue stream in light of competitive pressures. The IT industry has evolved most rapidly, putting companies unable to respond to market developments and technological uncertainty at a severe disadvantage.

At the core of this dilemma lies a classic trade-off between commitment and flexibility. Managers can stake a claim by making large capital investments today influencing their rivals' behavior or take a “wait-and-see” or step-by-step approach to avoid possible adverse market consequences tomorrow. The assessment and optimal management of strategic options is critical for firms to succeed in today's constantly changing